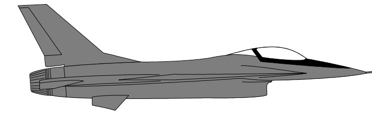
USAFA/DFAN
AERONAUTICS
RESEARCH CENTER

AIAA 2002-3268



Partial Leading Edge Forcing of a Delta Wing at High Angles of Attack

1st Flow Control Conference
24 – 26th June 2002, St. Louis, MO

Stefan Siegel*

Thomas McLaughlin

Julie Albertson

US Air Force Academy, Colorado Springs, CO

Sponsored by AFOSR, Dr. John Schmisseur

***Postdoctoral Fellowship from the National Research Council (NRC)**

Introduction

- **F/A 18 Vortex Breakdown**

Photo by NASA Dryden

- **Delta Wing Vortex Breakdown**

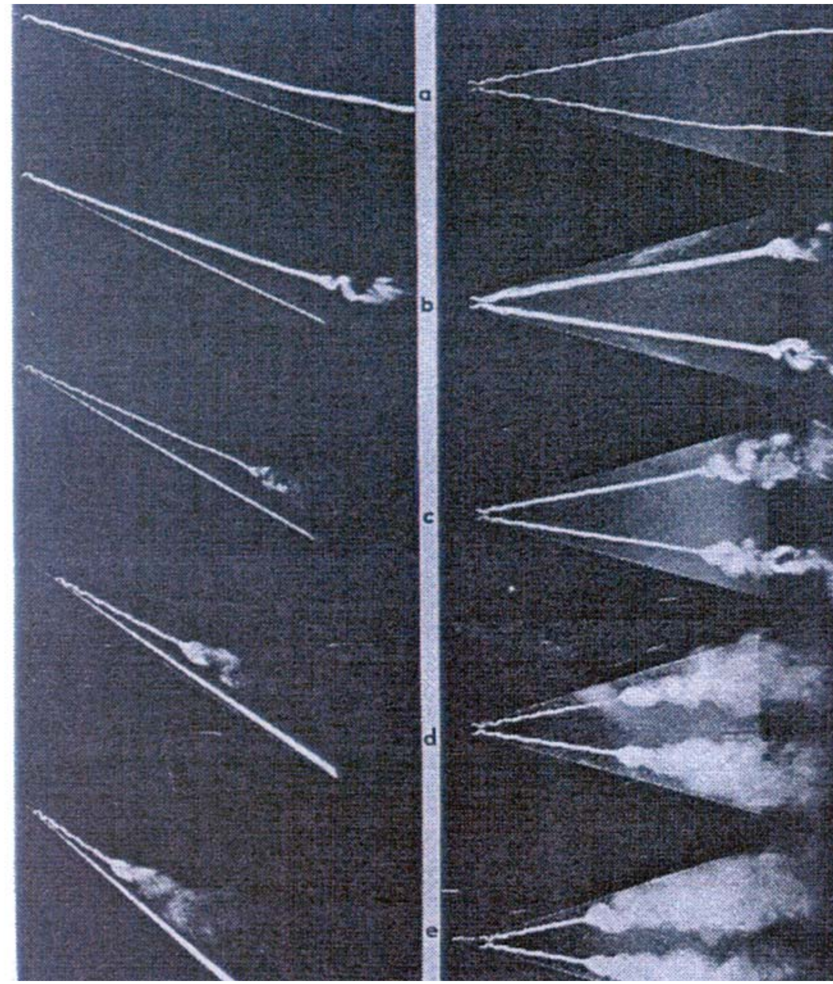
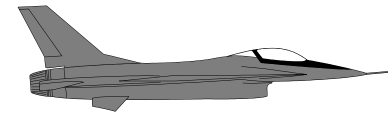


Photo by Werle

Previous Findings



Guy, Morrow, McLaughlin 1999:

(Wind Tunnel Pressure Tap Measurements)

- Lift increase by up to 38% using blowing and suction
- Stall Angle increased by 10° AOA

Siegel, McLaughlin, Albertson 2001:

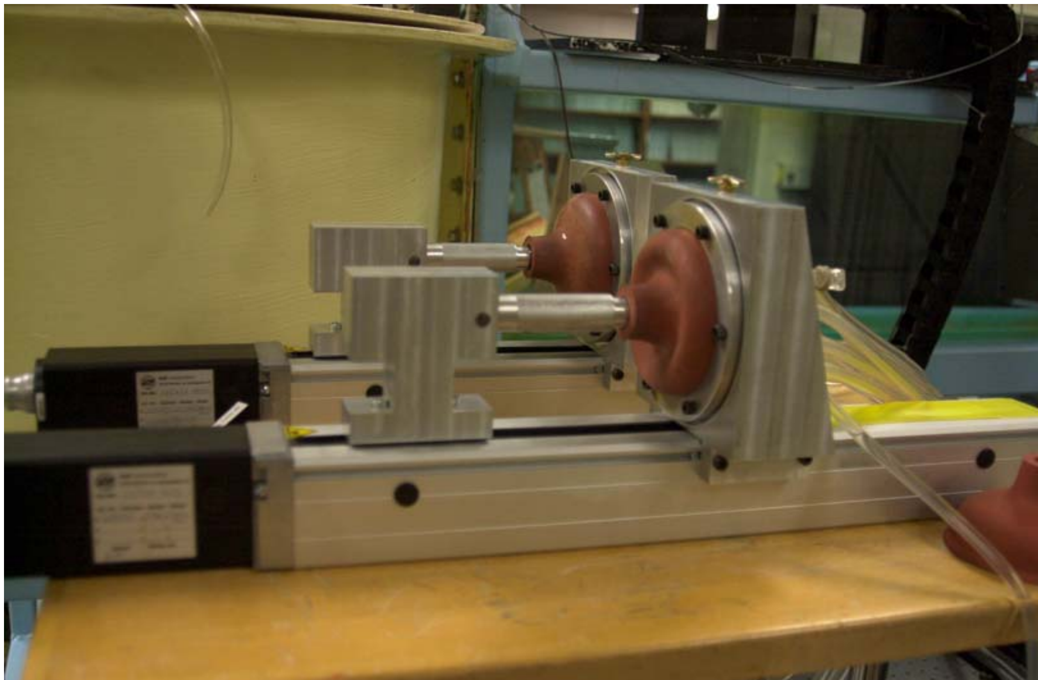
(Water Tunnel PIV Measurements)

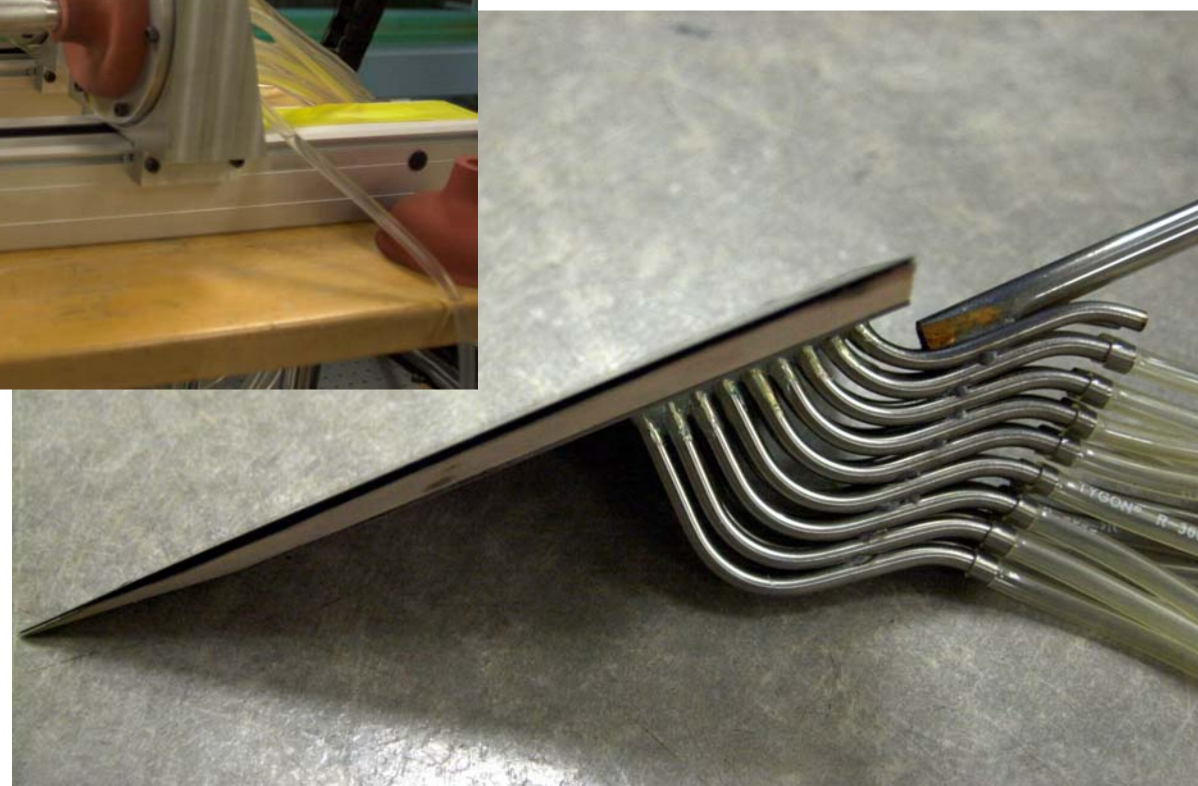
- No Delay in Vortex Breakdown
- Vortex travels along elliptical path
- Instead, Momentum Deficit downstream of Vortex Breakdown is reduced

Research Objective

- Investigate forcing along portions of the leading edge
- Use PIV to investigate local changes in the flow field
- Use wind tunnel pressure measurements to obtain normal force data.

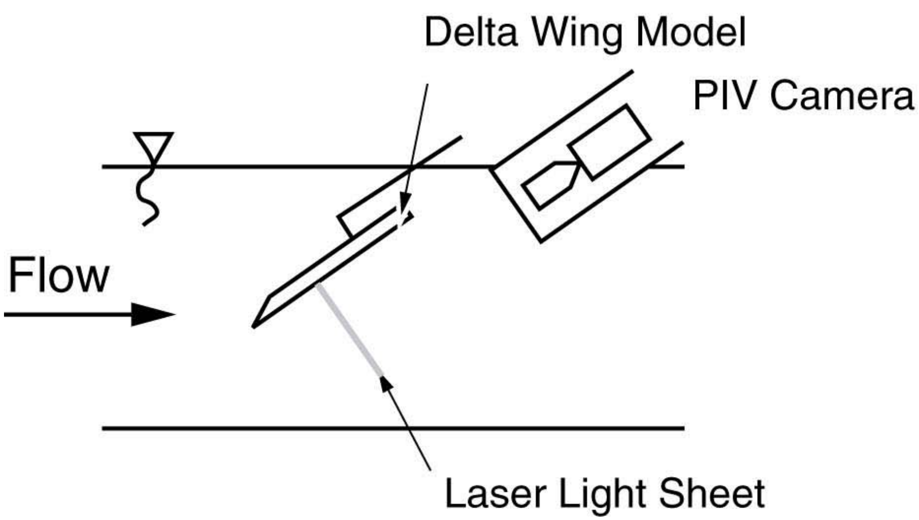
Water Tunnel Setup Pictures





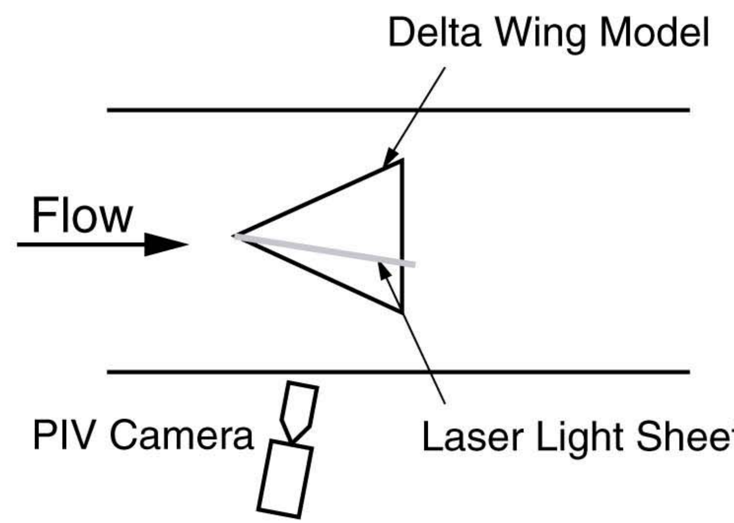
PIV Camera Setup

Measurements across vortex core



Side View of Test Section

Measurements along vortex core

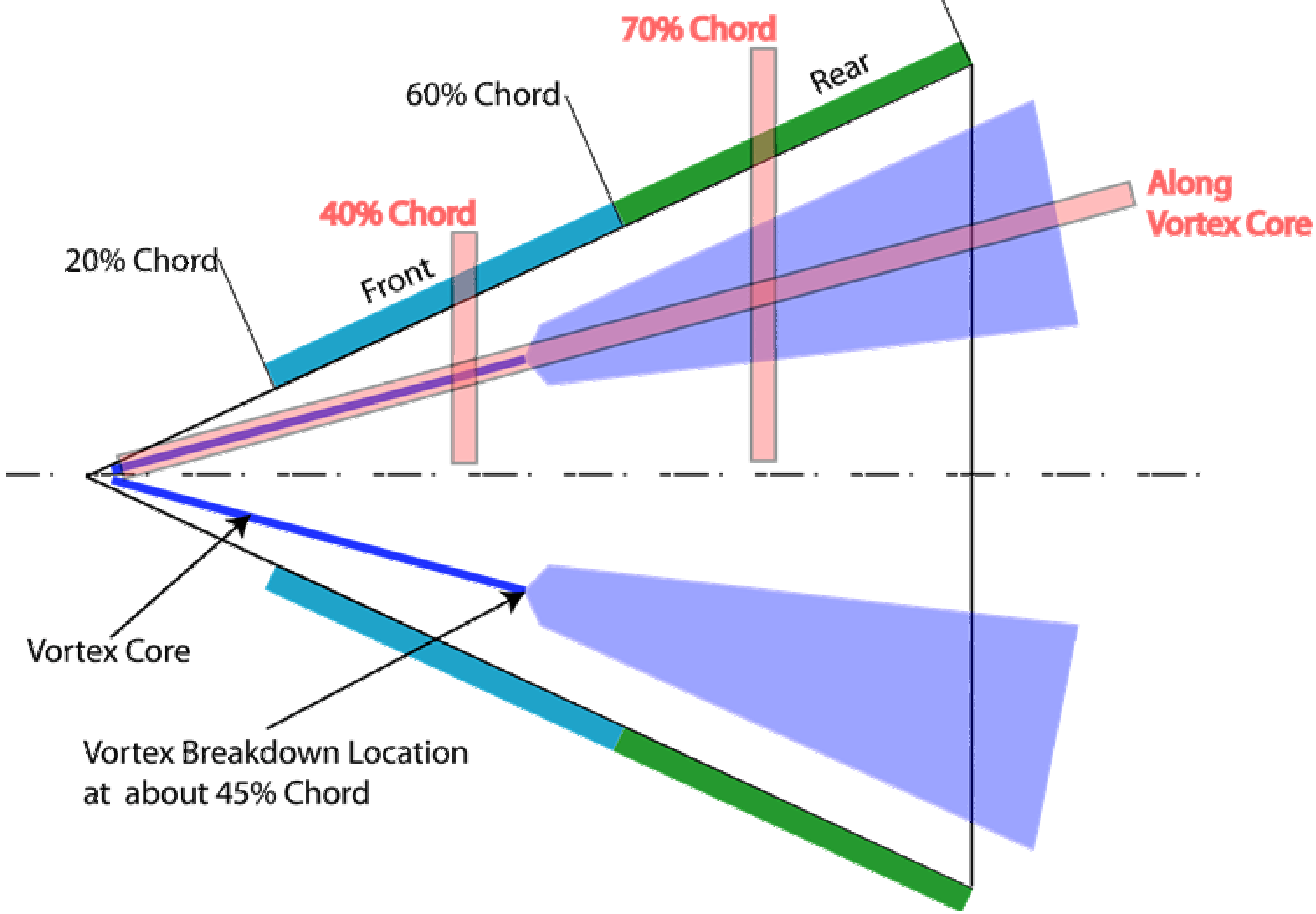


Top View of Test Section

PIV Measurement Procedure

- 32x32 pixel interrogation area
- (Phase) Averaging over 25 data sets
- Spatial averaging in a 3x3 vector area
- Forced data acquisition phase locked to forcing input
- Reference quantities for normalization are the freestream velocity, and the root chord

Flow Field Sketch



Experimental Parameters

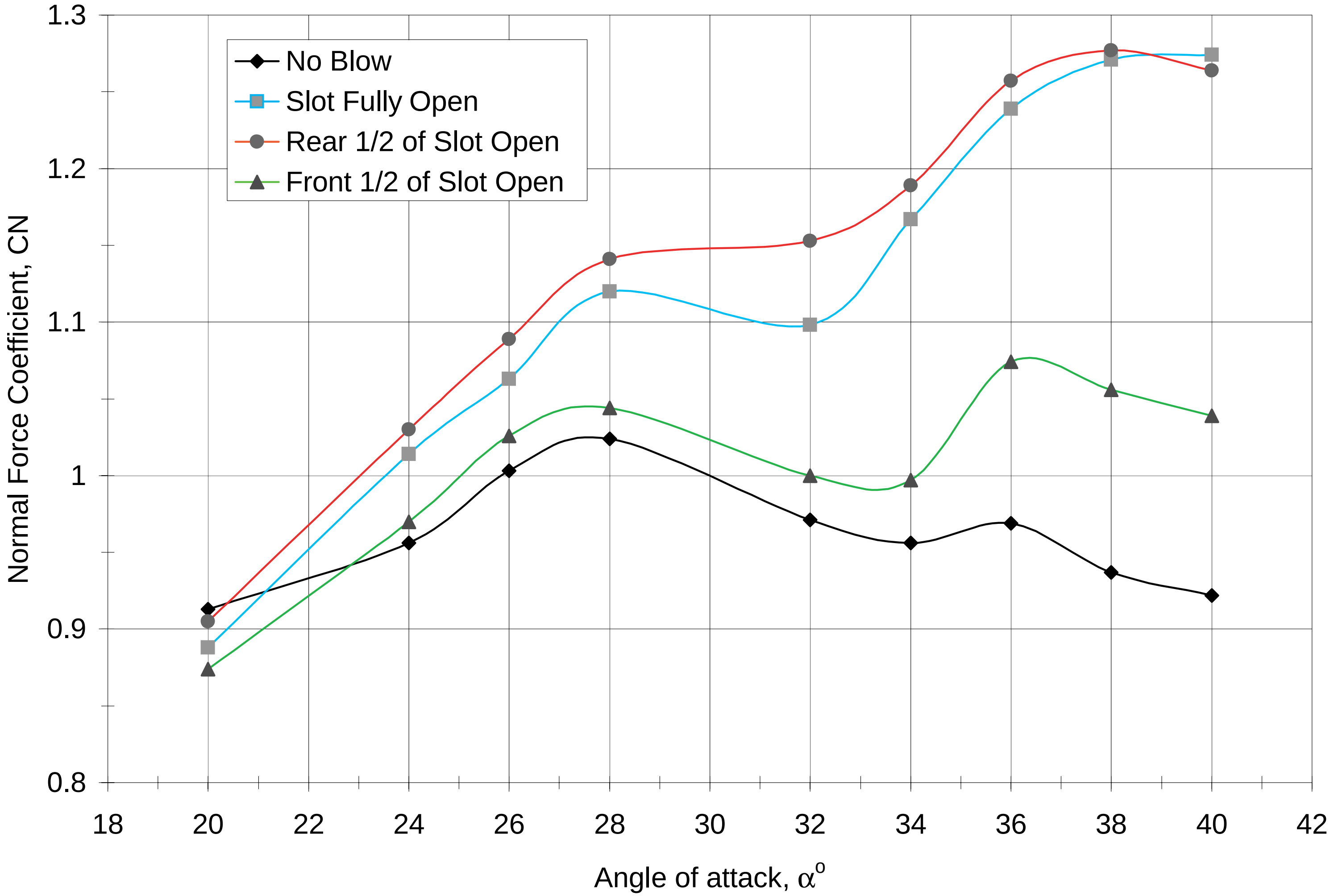
- 70° Delta Wing
- Water Tunnel Experiments
- 2D PIV Measurements
- AOA = 35°
- Re_C = 40k
- Periodic Blowing and Suction forcing parallel to wing surface, normal to and along entire leading edge.
- $u'(t) = \sin(\omega t)$
- Forcing Parameters:
  - F+ = 1.75 — $F+ = (f\, C_r) / U_{inf}$
  - $C\mu$ = 0.004 — $C\mu = 2(H / C_r)(\langle u' \rangle / U_{inf})^2$

Experimental Parameters - 2

- **Different sections of the leading edge used for Forcing:**
  - **Front Half (Water Tunnel: 20-60% Chord)**
  - **Rear Half (Water Tunnel: 60-100% Chord)**
  - **Baseline: Entire Leading Edge**
  - **Baseline: Unforced Flow Field**

USAFA/DFAN
AERONAUTICS
RESEARCH CENTER

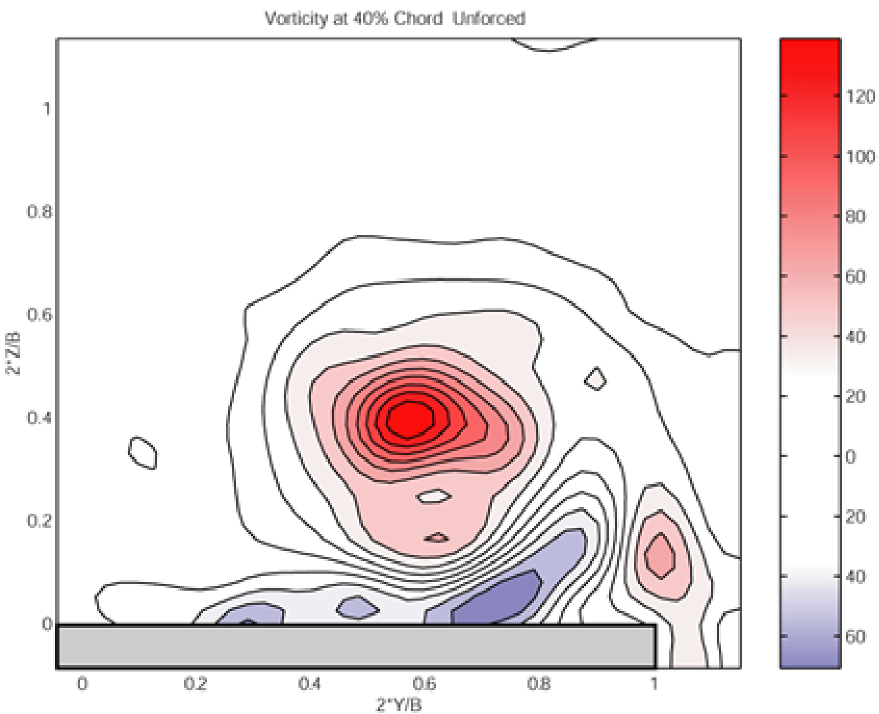
Wind Tunnel Normal Force

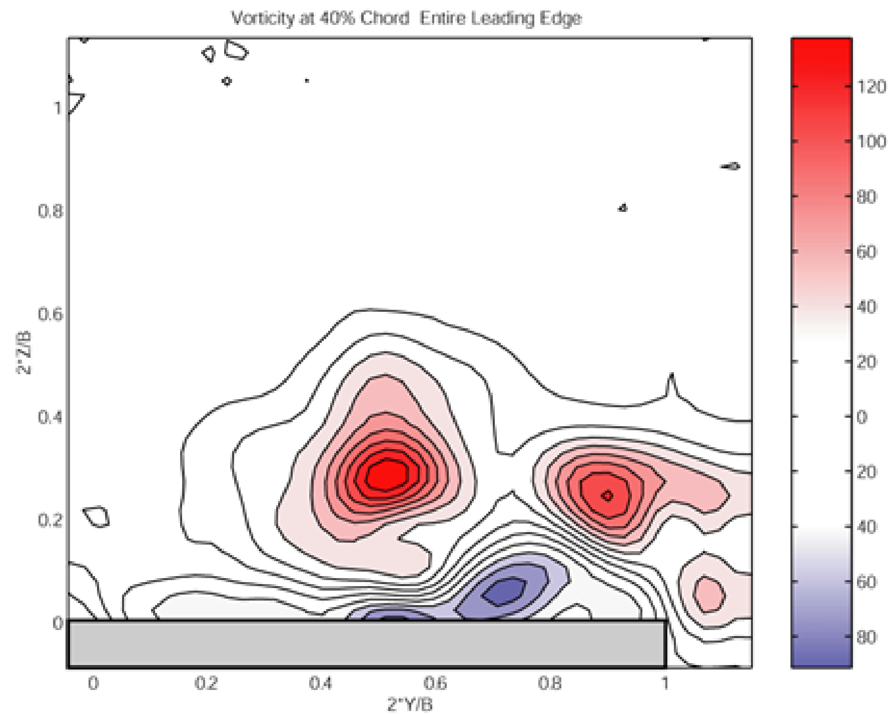


Courtesy Dr. Yair Guy

USAFA/DFAN AERONAUTICS RESEARCH CENTER

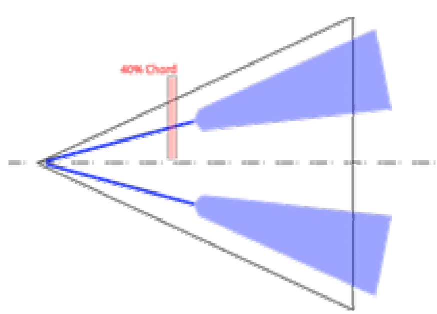
40% Chord Vorticity – Unf vs Entire



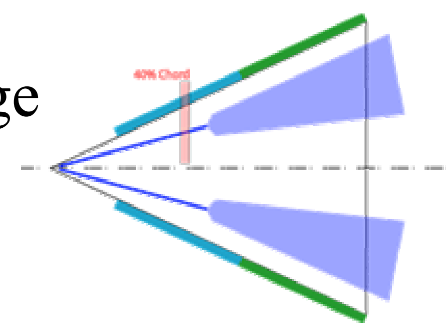


Phase: 60

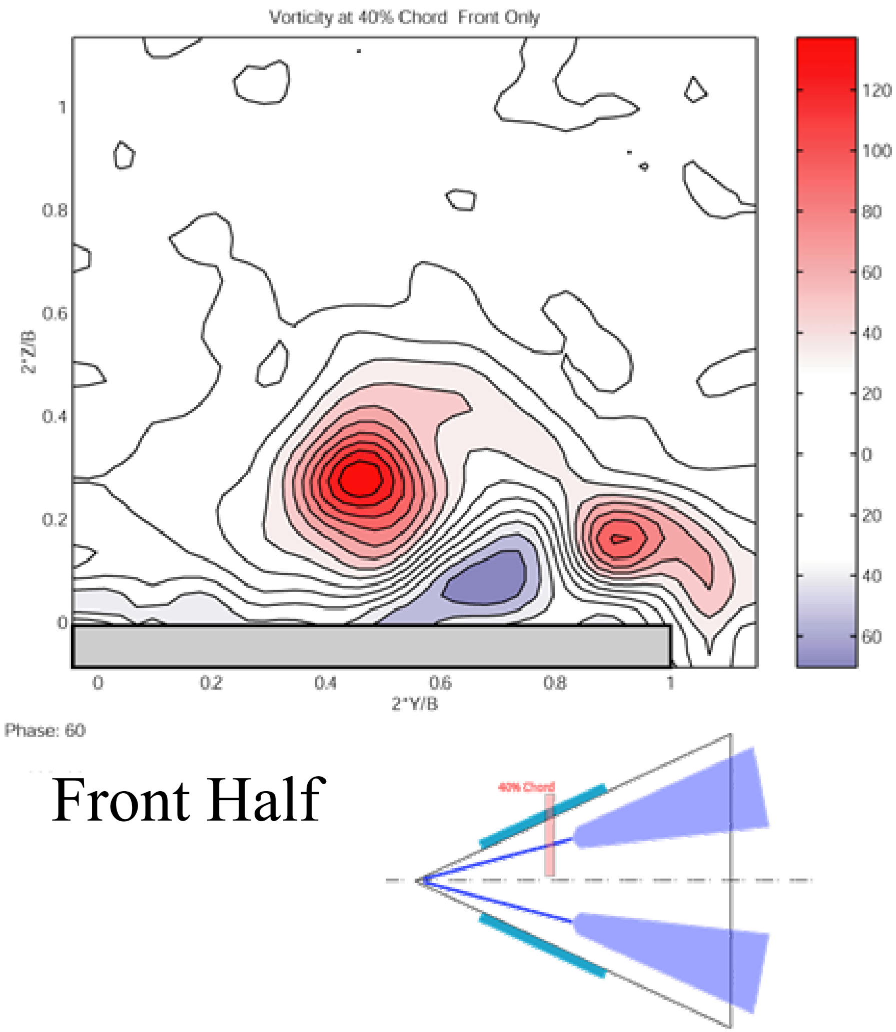
Unforced



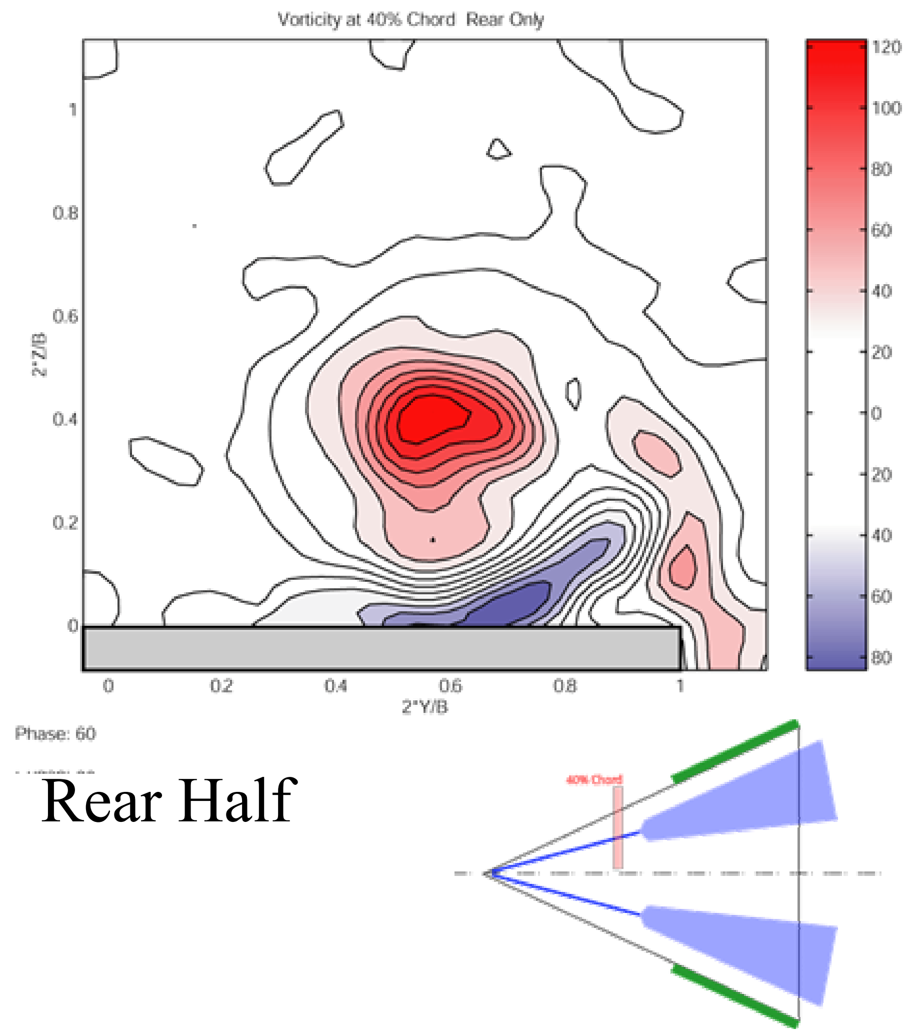
Entire Leading Edge



40% Chord Vorticity – Front vs Rear



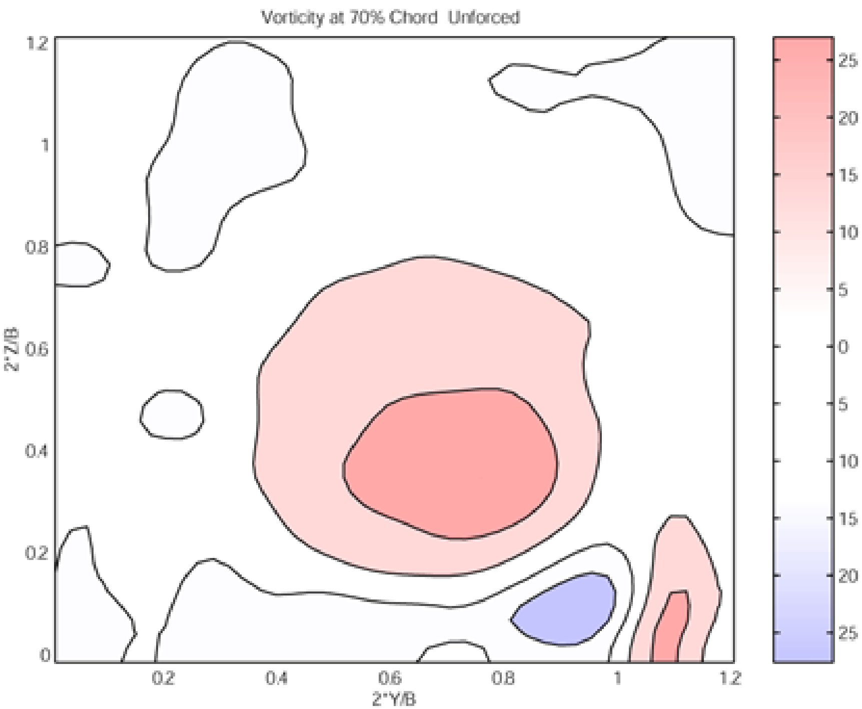
Front Half

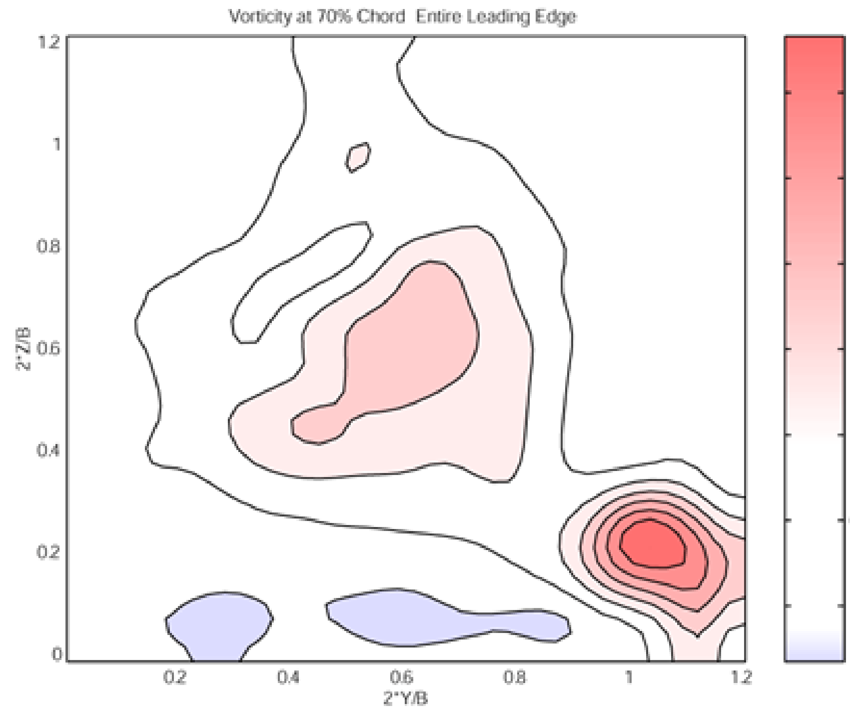


Rear Half

USAFA/DFAN
AERONAUTICS
RESEARCH CENTER

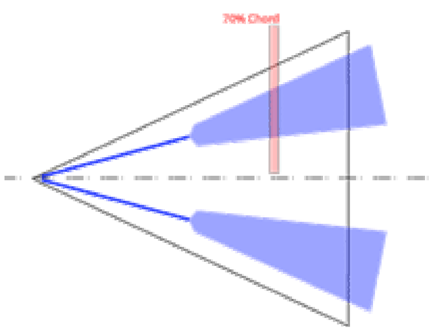
70% Chord Vorticity –Unf vs Entire



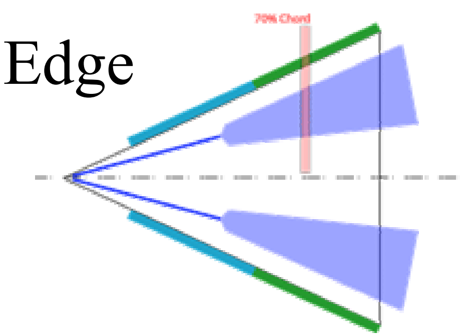


Phase: 60

Unforced

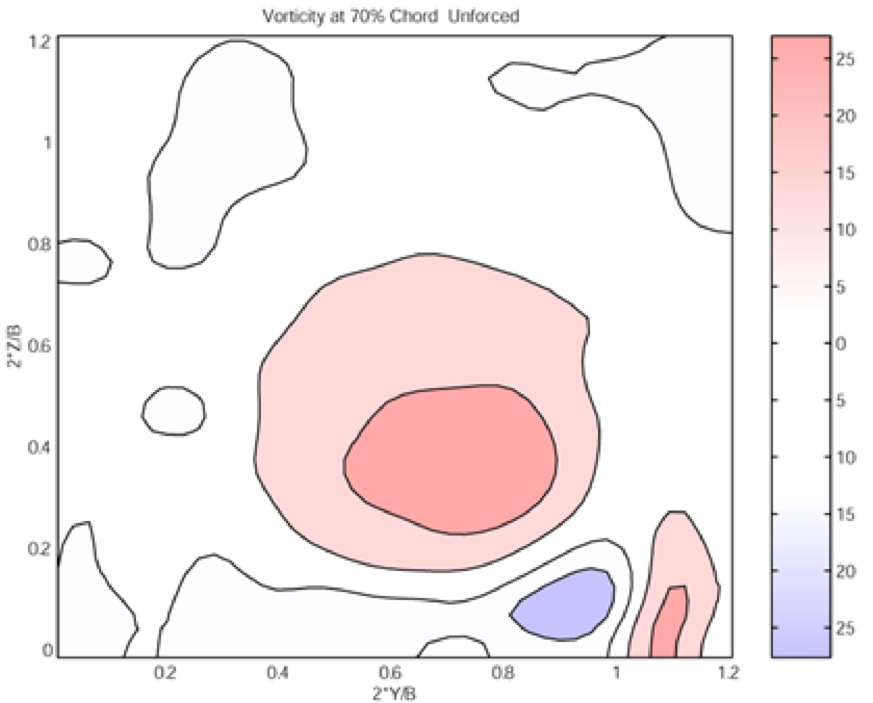


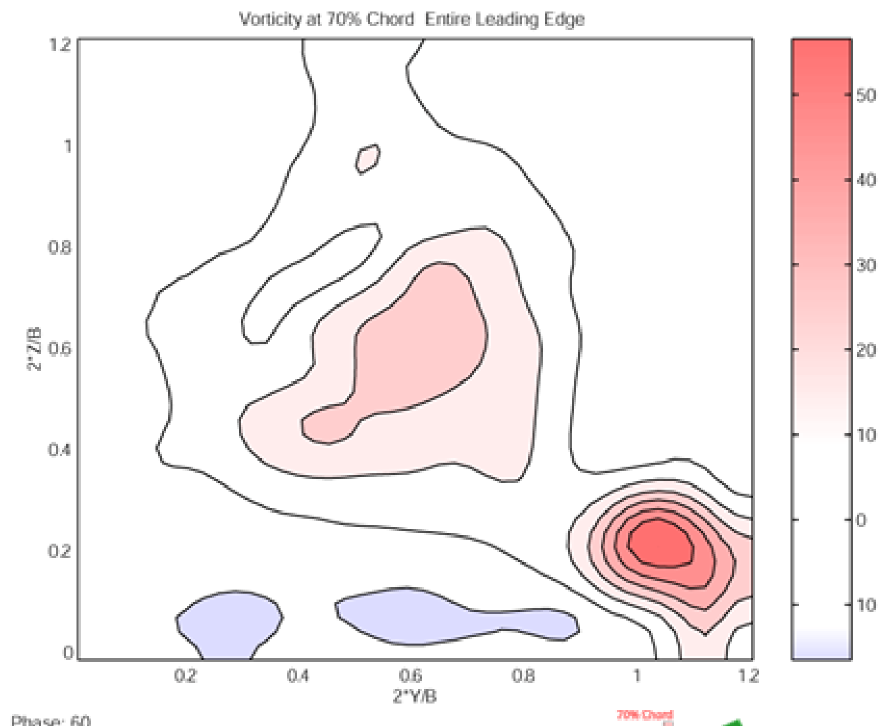
Entire Leading Edge



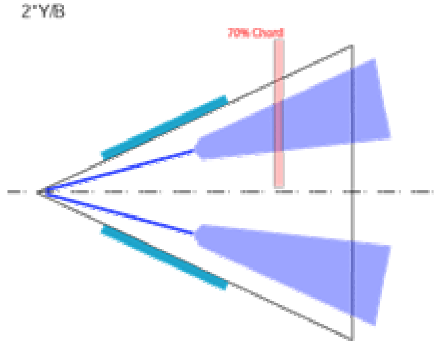
USAFA/DFAN
AERONAUTICS
RESEARCH CENTER

70% Chord Vorticity – Front vs Rear

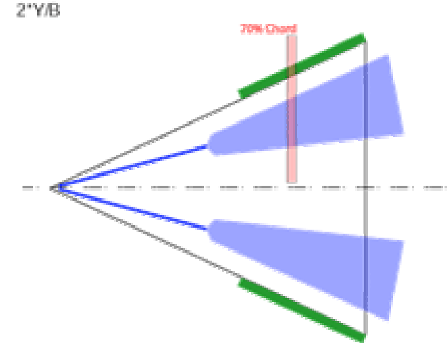




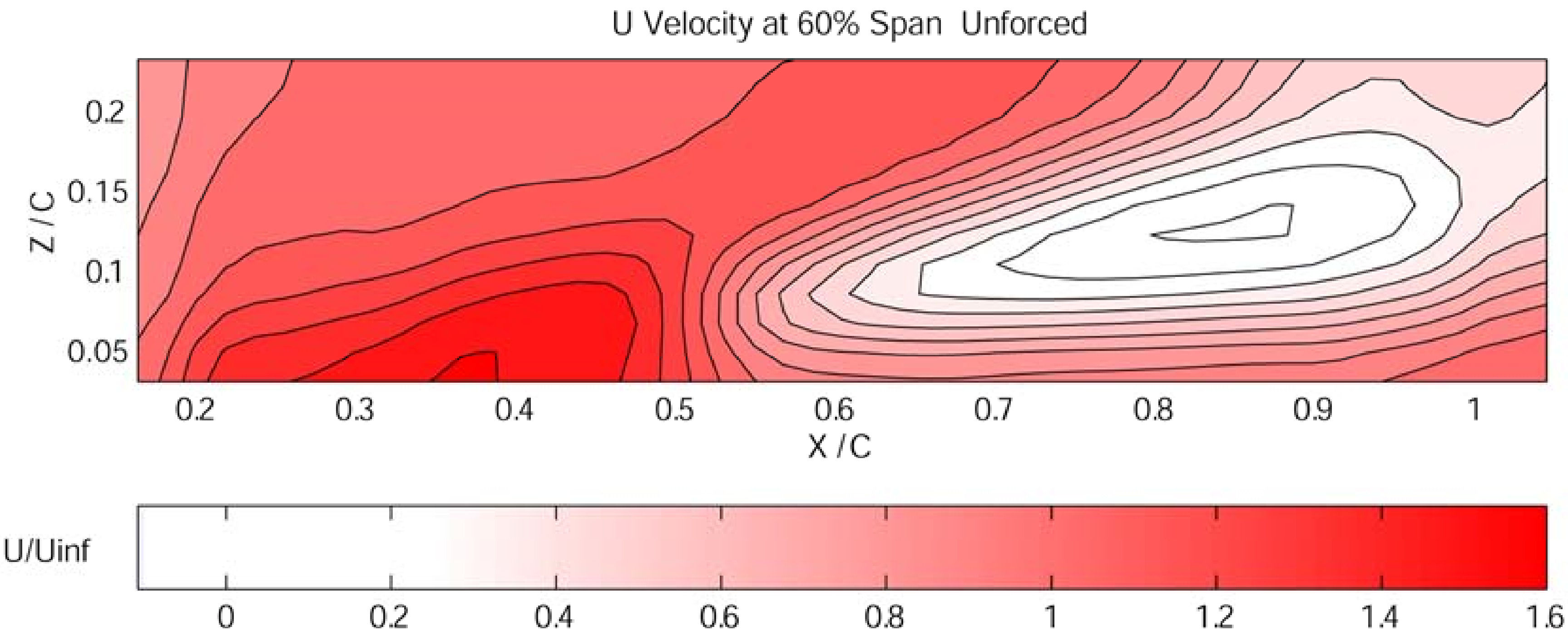
Front Half

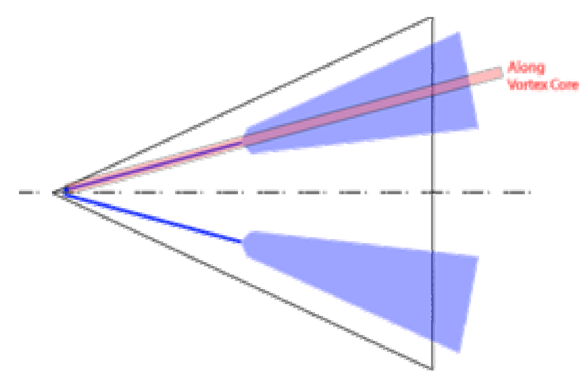


Rear Half



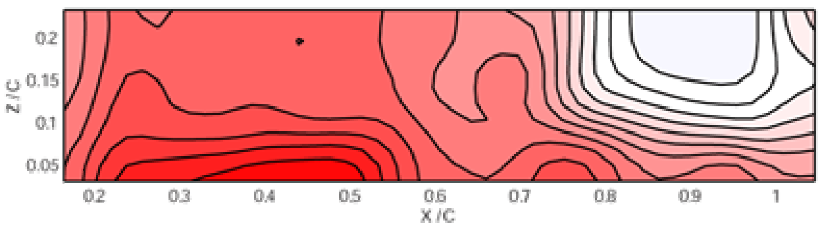
Axial Velocity Unforced



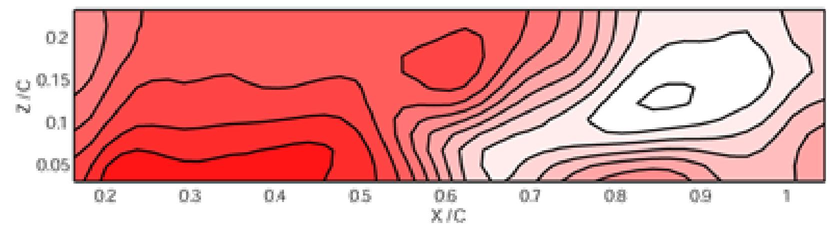


Axial Velocity Entire

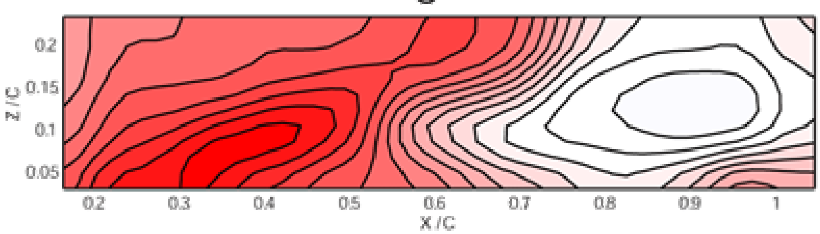
0 Degree



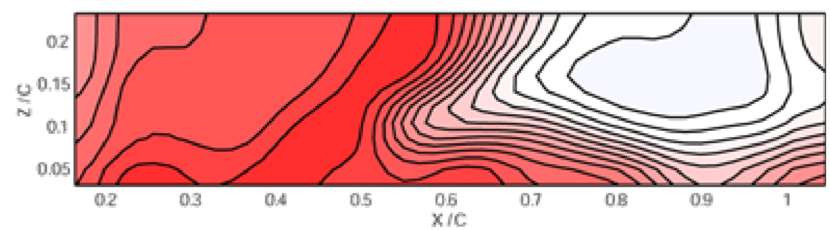
90 Degree

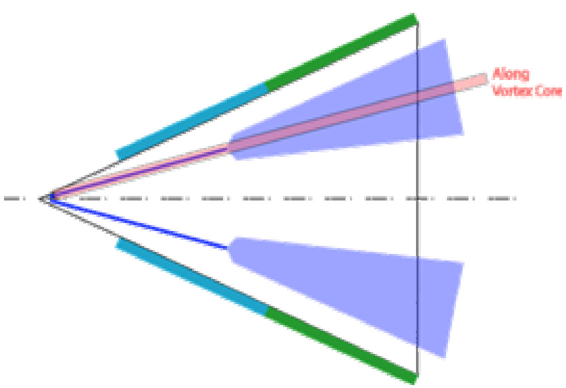


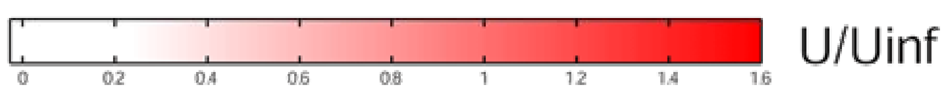
180 Degree



270 Degree



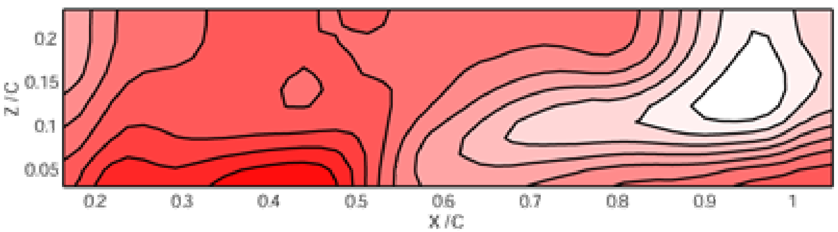




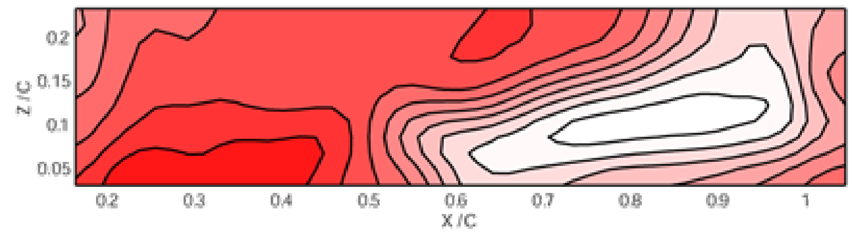
USAFA/DFAN
AERONAUTICS
RESEARCH CENTER

Axial Velocity Front

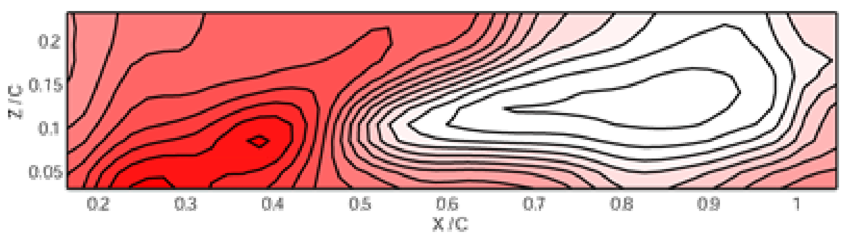
0 Degree



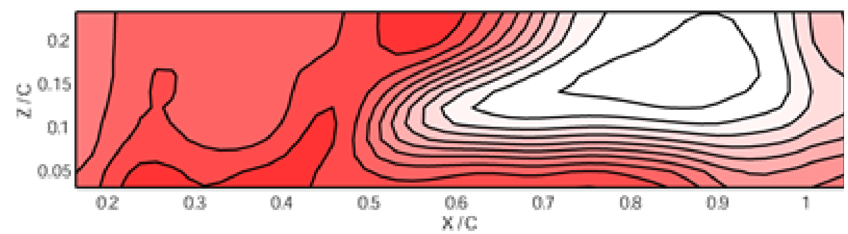
90 Degree

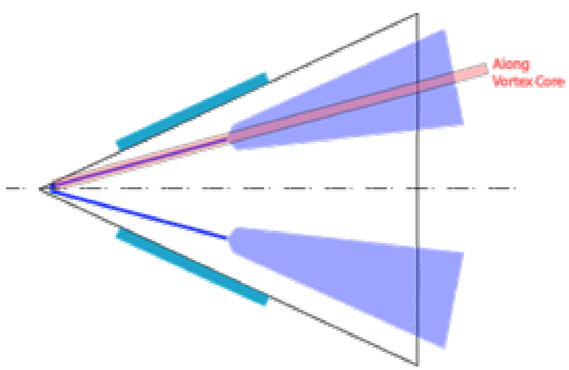


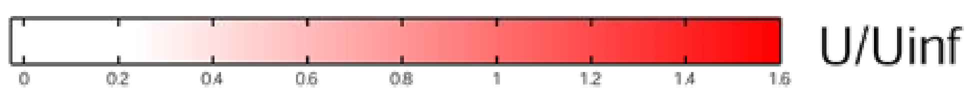
180 Degree



270 Degree



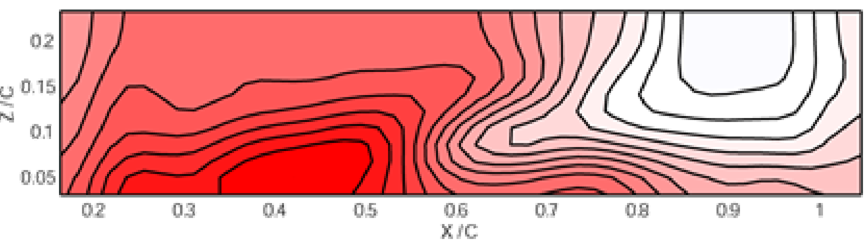




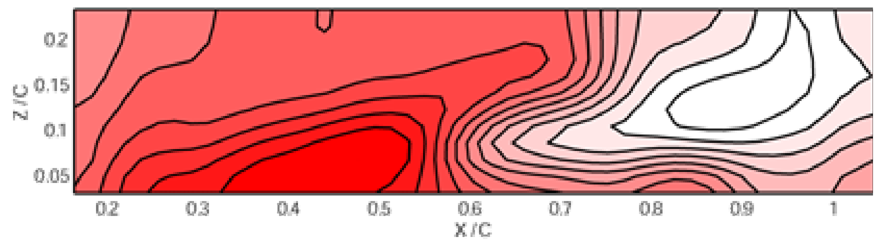
USAFA/DFAN
AERONAUTICS
RESEARCH CENTER

Axial Velocity Rear

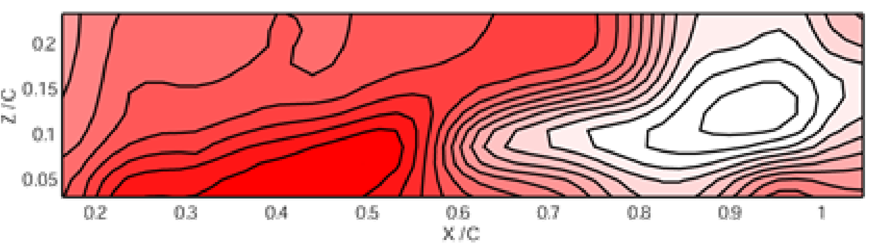
0 Degree



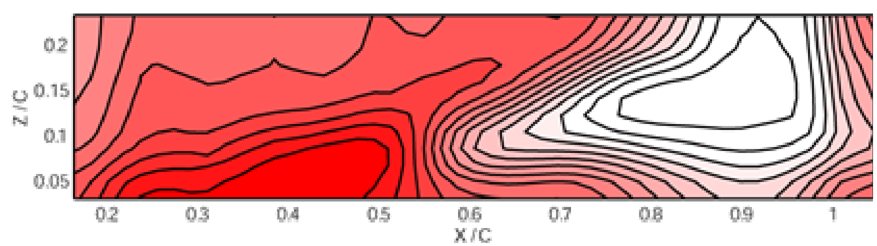
90 Degree

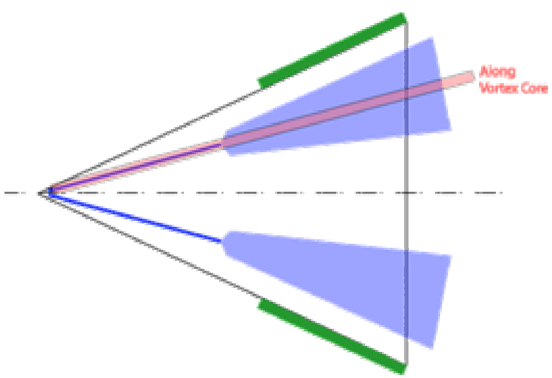


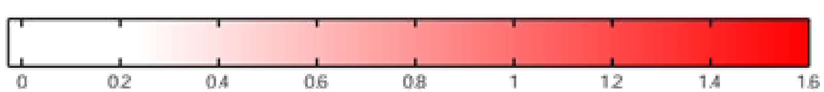
180 Degree



270 Degree

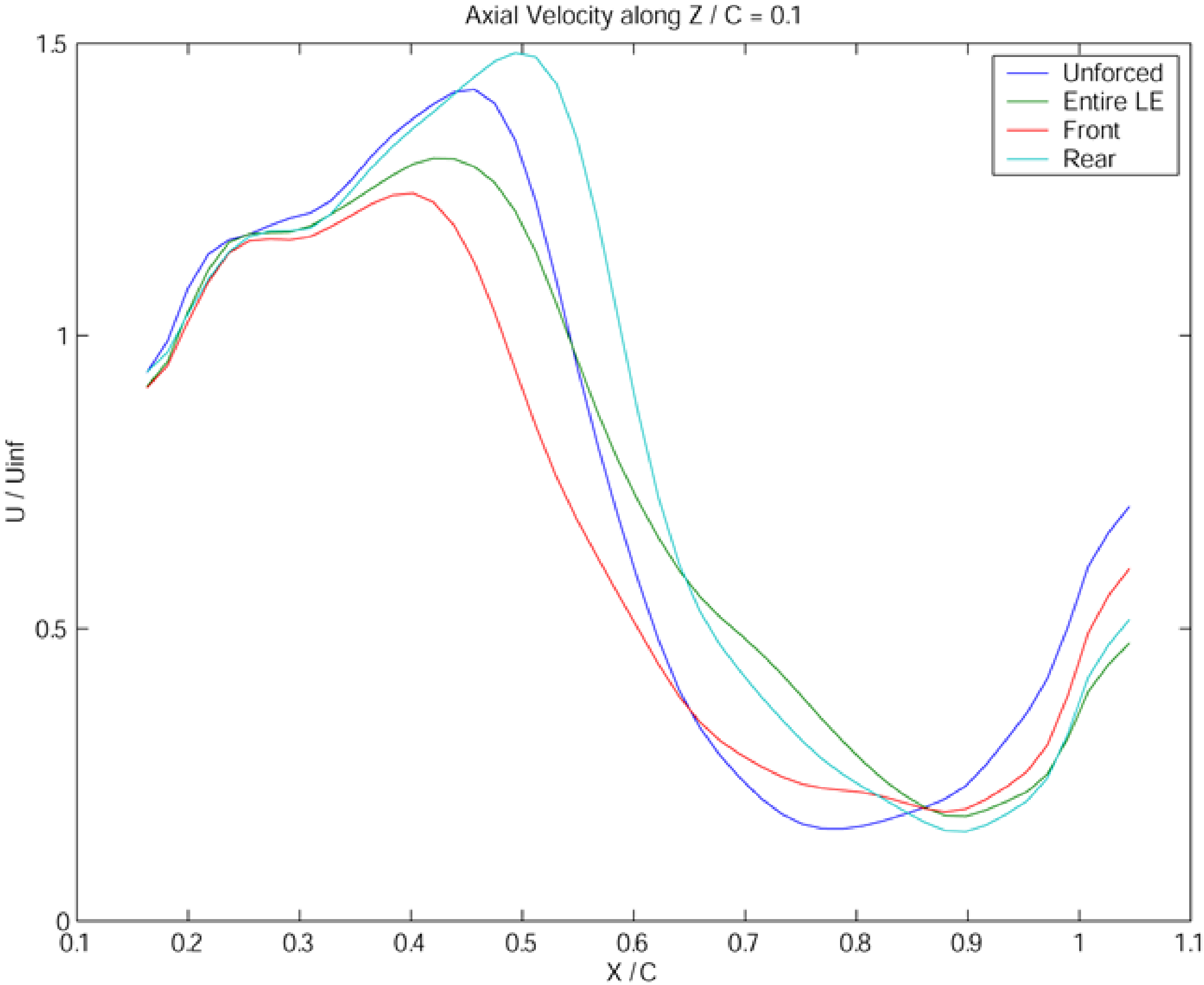




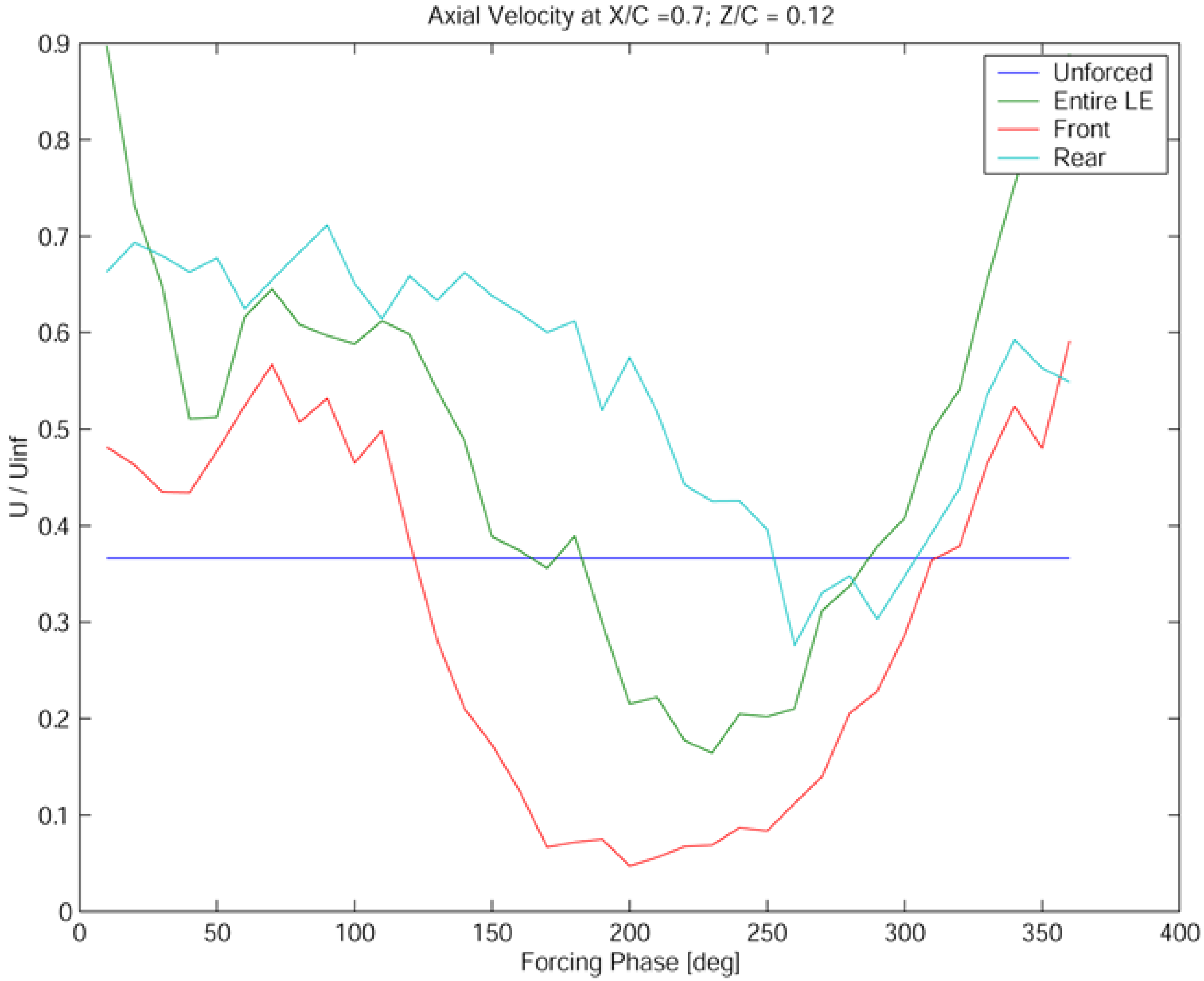


U/Uinf

Axial Velocity vs X/C



Axial Velocity vs Phase



Conclusions - 1

- **Pressure Measurements Wind Tunnel**
  - **Forcing along portions of the leading edge increases the normal force the most when applied towards the REAR of the delta wing**
  - **Forcing along the FRONT does NOT significantly increase the normal force**
  - **Forcing does not delay vortex breakdown**

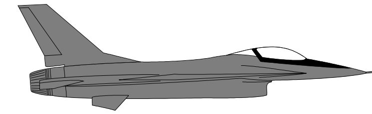
Water Tunnel PIV Measurements

- **A strong shear layer vortex forms along the portion of the leading edge where forcing is applied**

Conclusions - 2

- The shear layer vortex carries high axial momentum fluid over the wing
- If applied downstream of main vortex breakdown, the shear layer vortex decreases the axial momentum deficit
- The interaction between the shear layer vortex and the main vortex when forcing along the FRONT causes the main vortex to travel in a elliptical path spanwise and wing normal
- Vortex Breakdown Location was not significantly affected by the forcing

Outlook



- **Investigate spatially alternating blowing and suction along the leading edge forcing**
  - **Research at U Washington by C.B. Cain, Srigrarom et al.**
- **Gather more insight into details of the forced flow using CFD**
  - **CFD provides information on the entire 3D flow field, not just portions of it.**
  - **Under work at USAFA by Russ Cummings**